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CONTINUOUS-ROD WARHEAD LETHALITY TRIALS AGAINST B.29 AIRCRAFT FUSELAGES

(3/16, 1/4 and 5/16 INCH SQUARE-SECTION RODS)

by

R. G. E. MALLIN, A.F.R.Ae.S., G.I.Mech.E.

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SUMMARY

This Note records the results of the static detonations of 3/16, 1/4 and 5/16 inch square-section continuous-rod warheads, against Boeing B29 aircraft fuselages, four of which were loaded to simulate straight and level flight conditions at the attack station. In the attack of the mid pressure section (unpressurised) from 45° above abeam, only the 1/4 and 5/16 inch square section rods were capable of causing complete failure of the fuselage, whilst in the rear bomb bay section (aft of the wings) only the 5/16 inch rod produced a similar failure of the target.

Stress analyses have been made of the damaged targets to assist in the determination of the mechanism of target failure and of possible factors influencing rod effectiveness against aircraft fuselages. Some proposals for further work are included.

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1 INTRODUCTION

1.1 Previous trials[1,2], in which 3/16 and 1/4 in. square section continuous-rod warheads were fired against various stationary, unloaded, fuselage targets, showed that both sizes of rod were capable of severing up to 50% of the cross-sectional area of target structure, comprising skin, stringers and in some cases, longerons. From these results it was only possible to obtain an indication of the effectiveness of the continuous-rods in causing a structural kill of the target since the target residual strengths and the effect of target loading at the time of attack could not be determined.

1.2 In consequence, it was decided to make some limited firings of various sizes of continuous rods against sections of fuselages loaded to reproduce straight and level flight stresses in the structure at the point of attack. Boeing B29 aircraft were chosen as targets since their fuselage construction is conventional and is thought to approximate to that of the Soviet 'Badger' aircraft. Similar unloaded targets were included for the purposes of comparison.

1.3 The four firings described in this Note were made at the P. & E.E. (Shoeburyness) between June and October 1959 and are to some extent complementary to those made previously against Boeing B29 aircraft wings[3].

2 OBJECTS OF THE TRIALS

2.1 The objects of the trials were:-

(a) To determine the influence of flight loads on the effectiveness of continuous-rods when attacking aircraft fuselages.

(b) To compare the relative effectiveness of 3/16, 1/4 and 5/16 in. square-section continuous-rods when attacking various sections of loaded and unloaded aircraft fuselages, mainly of conventional construction.

(c) To determine the factors governing the effectiveness of continuous rods when attacking aircraft fuselages.

3 TRIALS PROGRAMME

3.1 Four warhead firings were made against structurally complete B29 aircraft fuselages, loaded to reproduce straight and level flight stresses at the attack station. Of these, two attacks were against the mid crew compartment and two against the bomb bay section aft of the wings.

3.2 In all but one firing, an unloaded fuselage section, similar to that being attacked in the loaded condition, was included as a secondary target. In the remaining firing, a Handley Page Victor aircraft rear fuselage section was attacked.

3.3 Generally, a continuous rod projected from a G.W. warhead is equally likely to strike the target from any direction, but due to the limitations imposed, in these trials, by target attitude, loading etc., it was decided to attack all primary targets from 45° above dead abeam relative to the attack station. The secondary targets, not being limited by loading conditions, were attacked from 45° above abeam and 60° off dead astern. These directions were considered to be typical of continuous-rod attack and likely to produce circumferential cuts in the target structure.

3.4 A summary of the firings and results is given in Table 1.

4 WARHEADS

4.1 Experimental models of Blue Jay and Red Dean warheads (3/16, 1/4 and 5/16 in. square section continuous rods) were used. Some details of these warheads are given in Table 2.

4.2 The warheads were mounted, 20 to 30 ft above the ground, on adjustable baseplates secured to a simple tubular structure. The slant distances from the warhead centre to the nearest point on the fuselage, at the attack station were adjusted, in all the firings, to be 85% of the rod theoretical maximum hoop radius. Thus, the slant ranges for the 3/16, 1/4 and 5/16 in. rod warheads were 20, 32 and 25 ft respectively.

5 TARGETS

5.1 The primary targets used in the trials were full-length Boeing B29 fuselages, assembled complete with inner wings, and mounted, in the normal flying attitude, on supports under the wing roots. Dead loads were applied to the upper surface of the tailplane to simulate flight stresses at the attack station.

5.2 It should be noted that two firings were made against sections of the fuselage which, in normal flight, would be pressurised. However, since the presence of such a pressurised compartment in the centre fuselage is most unusual on modern bomber aircraft it was considered to be more representative to attack these sections in the unpressurised condition.

The similarity of the structure in adjacent unpressurised regions showed that any effects, resulting from the strengthening of the structure of these sections to take pressurisation loads, to be negligible and consequently damage effects in pressurised and unpressurised sections could be compared.

5.3 The secondary targets consisted of two B29 centre fuselages (Stns.218-646), one B29 mid crew compartment (Stns.646-834) and one Handley Page Victor rear fuselage section (Stns.967-1045). These targets were simply supported in the required attitudes.

5.4 Details of the layout and loading of the primary targets are given in Appendix 1. General arrangements drawings of the target layouts are given in Fig.1 and shown pictorially in Figs.9 and 10.

5.5 Cross-sections of the B29 fuselage at the stations attacked, showing the location and dimensions of the various structural members, are given in Fig.2.

6 INSTRUMENTATION

6.1 The time taken by the rods to travel between burst point and target was measured by a micro-second counter chronometer, actuated by an infra-red photocell directed at the warhead and six "make screens" fitted on the fuselage at the attack station. The mean rod velocity was calculated using the average of the times obtained from each of the six channels. Striking velocities were then computed from rod retardation data and are given in Table 1.

6.2 In all firings, the instrumentation was provided and operated by the staff of P. & E.E.(S).

7 TRIALS PROCEDURE

7.1 In each trial, after the assembling and positioning of the targets, the primary target was loaded. The warhead was then detonated and the resulting damage recorded. In the two cases where the loaded target did not fail, a steadily increasing down load was applied to the fuselage below the tailplane until failure occurred at the attack station. The failing load required was noted and the residual strength of the target, after attack, determined.

8 TRIALS RESULTS

8.1 The damage to each of the fuselage targets from rod attack is summarized in Table 3 and illustrated in Figs.3-8 and 11-14.

8.2 The residual strengths of the primary targets which did not fail initially, are given in Table 1 together with mean rod velocities and approximate striking velocities for each firing.

9 ANALYSIS OF TARGET DAMAGE

9.1 Primary targets

9.1.1 To obtain information on the mechanism of target damage and to provide indications of the factors likely to affect continuous-rod effectiveness against aircraft fuselages, structural analyses were made of the four primary targets damaged in the trials.

9.1.2 The method of analysis was the same as that used by the Boeing Airplane Co. in the design of the B.29 and which is described in a report of the Sidewinder warhead effectiveness issued by N.O.T.S. in the U.S.A.[4]. Visual examination of the primary targets had shown that:-

(a) failures were almost wholly tensile,

(b) frame damage was negligible,

(c) exit side damage was relatively small.

Thus, the analyses were made for pure bending loads only, exit side and frame damage being neglected. Details of the analyses are given in Appendix 2.

9.1.3 The maximum nominal stresses occurring in the target structures, immediately after rod attack, and, in two cases, at the commencement of failure under increased load, were calculated and are as follows:-

Firing	Maximum stress (lb/in^2)		Condition
	Tensile	Compressive	
No.1 (1/4" C.R. v. Stn.768)	11,500	7,055	At failure after rod attack.
No.2 (3/16" C.R. v. Stn.768)	10,400	5,690	After rod attack.
	16,400	8,940	At failure under additional load.
No.3 (1/4" C.R. v. Stn.566)	15,680	8,020	After rod attack.
	22,600	11,500	At failure under additional load.
No.4 (5/16" C.R. v. Stn.566)	25,500	9,950	At failure after rod attack.

In each case, the maximum nominal stresses occurred at the ends of the rod cut. As the ultimate tensile strength of the material used in the B.29 fuselage (24 ST. aluminium alloy) is of the order of 60,000 lb/in^2, it appears highly probable that fuselage failure was initially due, in each case, to the stress concentration at the tensile loaded end of the rod cut giving rise to a fast propagating crack.

9.1.4 If this assumption is true it is apparent that actual values of nominal stress alone are of little use in determining whether a structure will fail or not, the overriding factor being the magnitude of the stress concentration. In the trials this factor appeared to vary between approx. 2 and 5, probably dependent on the cut end shape. Should a fuller understanding of the magnitude and occurrence of stress concentrations be obtained in the future, then the values of nominal tensile stress will become increasingly important.

9.1.5 It has been noted in these and other trials[1,2,3] that the initially continuous rod hoop, in its passage through the attack face of typical aircraft target structures, is broken up into numerous small fragments as a result of the impact (see Fig.12). This fact suggests that the maximum possible length of <u>continuous</u> cut on a circular section fuselage, is that part of the circumference bounded by the two tangents to the fuselage drawn from the position of warhead detonation. Since the nominal stresses in a target arising from rod damage are largely dependent on the amount of structure severed by the rod and hence on the length of the continuous cut in the attack side, it is of interest to compare the lengths of cut obtained in the trials with the apparent maximum obtainable. This comparison is made in Table 3 and it will be seen that in all cases the rods produced cuts greater than 90% of the theoretical maximum with the exception of the 1/4 in. rod attacking Stn.566 of the primary target, where only 74% was achieved. This fact, and the shape of the rod cut on the fuselage (Fig.13A), indicates that this rod did not develop fully, as in the other firings. This result, however, must not be fully discounted for assessment purposes, as it may lie within the scatter to be expected in warhead performance. The relatively short length of cut accounts for the low nominal tensile stress produced in the target and possibly for the ineffectiveness of the rod warhead in this particular firing. Also included in Table 3 are the approx. percentages of the total cross-sectional area of the targets severed by the rods in (a) the attack side and (b) the attack and exit sides combined. It will be seen that the percentage difference in structure severed for targets which did fail and those which did not was of the order of 3 to 5% for attack side damage. This, though small, could be significant, bearing in mind the location of the additional severed material in a highly stressed tensile loaded region. When exit damage was included, the percentage difference rose to between 5 and 7%. However, since the exit damage tended to be concentrated on or near the neutral axis of the damaged fuselage, it is thought to have had little effect on the target residual strength.

9.1.6 A further point arising from target damage analysis was that the length of rod cut below a line joining warhead and target centres was, in all cases, equal to or greater than the length of cut above this line, and is probably attributable to the effect of the ground on rod deployment near the lower extremities of the cuts.

9.2 <u>Secondary targets</u>

9.2.1 From the results of Firing No.2, in which the same section of the B.29 fuselage was attacked by a 3/16 in. rod in both the loaded and unloaded condition from the same direction of rod approach, it appeared that target loading had little effect on the extent of the damage, the length of cut and amount of structure severed on each target being very similar.

9.2.2 The results of Firings Nos.3 and 4 against the secondary targets showed that the effect of changing the direction of attack from 45° above abeam to 60° off astern was to slightly decrease the amount of skin and stringer material severed, but this was offset by the severance of several frames. Exit damage was reduced to negligible proportions. The 5/16 in. rod was also shown to be capable of damaging longeron members adjacent to the skin to a greater extent than the 1/4 in. rod.

9.2.3 The low percentage (31%) of structure severed by the 1/4 in. rod when attacking the Victor rear fuselage was due to the presence of strong structural members located near the fuselage centre line which the rod was unable to damage severely, having already passed through the fuselage skin.

10 INTERPRETATION OF DAMAGE ANALYSIS

10.1 Apart from the more obvious factors which may influence rod effectiveness, such as rod size, velocity, material and construction, the trials results and subsequent analysis show that certain other factors should be considered. These are discussed briefly below:-

(a) Shape of rod cut extremities

If the theory that failure of the loaded fuselages attacked in the trials was by the propagation of a fast crack from the tensile loaded extremity of the rod cut, then the nature and shape of the cut end may be of great importance since it will determine the magnitude of the stress concentration at that point. For example, the stress concentration factor will be much less at a round-ended cut than at a sharp-ended one. The factors affecting cut-end shape have not, as yet, been determined but will largely depend on rod behaviour during its passage through the target. Clearly, the effects of stress concentrations will be restricted to rod cuts having one end in a highly loaded tensile surface.

(b) Direction of attack

In a fuselage target, the direction of attack will determine the radial location of the rod cut. The stress analyses made on the damaged targets show that cuts in the tensile (upper) and compressive (lower) loaded surfaces will be considerably more effective than cuts in the shear loaded (side) surfaces since the former are designed to take the majority of the fuselage bending load and hence contain a large proportion of the target cross-sectional material. Furthermore, damage to the compressively loaded lower surfaces should be the most effective because the allowable stresses are lowest in this region due to the instability caused in the surface by the severing of stringers, longerons etc.[5] It has also been found that a small extension of the rod cut near the top of the fuselage (in tension) will considerably raise the maximum nominal tensile stress resulting from the cut.

(c) Fuselage frame damage

The trials have shown that the three sizes of rod used were capable of severing fuselage frames. Owing to the direction of attack chosen, however, the primary targets suffered negligible frame damage and this was not considered in the stress analyses. Firings against the secondary targets showed that, for other directions of attack, frame damage could be severe and would almost certainly contribute substantially to the loss in strength of a fuselage target. This effect would be particularly marked where it occurred in tension loaded surfaces through the loss of frame support to the stringers and skinning[5].

(d) Warhead maximum hoop radius and stand-off distance

These are directly related to the extent of the target exposed to rod attack and thus appear to have a direct bearing on the length of the rod cut in the target. The stand-off distance will also affect the degree of rod hoop deployment. Thus zig-zag or straight line cuts can be obtained.

(e) Exit side damage

It is apparent that the nature, extent and location of damage to the rod exit side of a fuselage target may, in certain cases, be the deciding factor as to whether a fuselage fails or not. The trials have shown that, in general, the larger the rod size the more exit damage is caused. However, the trials were done against virtually empty structures and since, in practice, the majority of an aircraft fuselage will be filled with fuel tanks, bombs and equipment, it would follow that exit damage in these sections could be negligible.

11 CONCLUSIONS

11.1 The main conclusions which may be drawn from the trials are:-

(a) From the results of a single firing, against two targets, there appears to be no significant visual difference in the damage obtained from similar attacks with 3/16 in. square section continuous rods against B.29 fuselage structures in the unloaded and 'loaded to 1g' condition.

(b) Under the conditions of the trial, only the 1/4 in. and, by inference, the 5/16 in. rods, are capable of defeating the B.29 fuselage at Stn.768 when attacking from 45° above abeam and at a stand-off of 85% of the theoretical maximum hoop radius.

(c) Under the same conditions, only the 5/16 in. rod is capable of defeating the B.29 fuselage at Stn.566.

(d) The fuselage sections which did not fail under rod attack i.e. 3/16 in. rod against Stn.768 and 1/4 in. rod against Stn.566, were found to be capable of supporting 1.5 and 1.75 times, respectively, the level flight loads before failure occurred.

(e) All three sizes of rod are capable of producing continuous cuts, on the attack side of a fuselage target, of length greater than 90% of the apparent maximum arc possible, and also of severing all skin and light members in contact with the skin over the length of the cut.

(f) Firings against fuselage sections at directions of attack of 45° above abeam and 60° off astern resulted in similar attack side damage. From the latter direction, however, exit side damage was reduced and considerable frame damage achieved.

(g) Damage to the 'Victor' target showed that a 1/4 in. rod is capable of severing typical sandwich skin structure comprising longerons, double skin and closely spaced stringers and that exit side damage is small when internal diaphragms are present.

(h) The trials results and interpretation show that it is not possible to determine the residual strength of a damaged target by visual examination or simple stress analysis only. It appears essential that, until a better understanding of stress concentration effects is obtained, firings should be made against loaded structures and, if necessary, these should be loaded to destruction after firing.

(j) The trials have also shown that the following factors may have a significant influence on rod effectiveness against fuselage targets:-

(i) Shape of rod cut extremities

(ii) Direction of rod attack

(iii) Damage to fuselage frames

(iv) Warhead maximum hoop radius and stand-off distance

12 FURTHER WORK

12.1 It will be seen, from the work described in this Note, that, in order to assist in the making of rod warhead lethality assessments, much information on rod effectiveness against fuselages, of various forms of construction, remains to be investigated. It is suggested that further warhead firing trials should be made to determine:-

(a) the influence of direction of attack, for both circumferential and angled cuts, on fuselage residual strength, the trials to be combined with stress analysis,

(b) the influence of rod size, velocity, maximum hoop radius and warhead stand-off distance on the length and type of rod cut in both loaded and unloaded fuselage sections.

It is also considered essential that further investigations, probably using theoretical and/or model techniques, should be undertaken to determine:-

(a) the influence of cut end shape on the magnitude of stress concentration factors produced in tension loaded surfaces.

(b) the influence of frame damage on fuselage residual strength.

13 ACKNOWLEDGEMENTS

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(a) The Superintendent, P. & E.E. (Shoeburyness) and his staff for their co-operation in preparing and carrying out the trials, and for permission to reproduce the photographic illustrations.

(b) The Director, A.R.D.E. and personnel of P8 Division for their co-operation in the supply of the continuous rod warheads.

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ATTACHED:

Appendix 1 and 2
Tables 1-3 and App2, 1-4
Figs.1-8 SME 85423/R - SME 86430/R
Figs.9-14 Neg.Nos. 151,434 to 151,447
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APPENDIX 1

DETAILS OF TARGET LAYOUT AND METHOD OF LOADING

1 TARGET LAYOUT

1.1 The primary targets used in the trials consisted of full-length Boeing B.29A fuselages assembled complete with inner wings and tail-unit. To simplify the method of loading the whole target assembly was mounted in the normal flying attitude supported by two reinforced concrete pillars, located under each wing root, with shaped wooden cradles under the front and rear spar booms, as shown in Figs.9 and 10. To support the counterbalance weights located in the aircraft nose, a sandbag cradle was constructed under the front fuselage.

1.2 The secondary targets, which were not loaded, were in all cases simply supported at their extremities by sandbag cradles and/or tubular scaffolding.

2 TARGET LOADING

2.1 It was desired that the loading of the primary targets should produce stresses in the targets, at the stations attacked, representative of those occurring when the aircraft was flying straight and level in non-turbulent air at an all-up weight of 117,000 lb (i.e. with full bomb load and half fuel load). The required conditions were as follows[6]:-

Condition \ Fuselage station	Stn.768	Stn.566
Bending moment (B.M.)	2,314,000 lb/in.	4,763,000 lb/in.
Shear force (S.F.)	8225 lb	18,300 lb

2.2 It was found that to reproduce these conditions exactly would require a very complicated loading system and it was finally decided to load the fuselage by means of weights placed on the aircraft tailplane such that the percentage errors in the B.M. and S.F., at the stations attacked, were the same.

Thus the conditions under which the fuselages were attacked were as follows:-

Condition \ Fuselage station	Stn.768	Stn.566
Bending moment (B.M.)	2,159,800 lb in.	5,736,000 lb in.
Shear force (S.F.)	8885 lb	14,845 lb

It will be noticed that the errors involved in using this simple system of loading are appreciable at Stn.566. However, the design criteria for the B.29 fuselage is the landing case at high weight conditions, and hence the actual strength of the fuselage may be more than ten times that required for 1g level flight[4]. It was, therefore, considered that the errors present would not greatly affect the trials results.

2.3 In all cases where the targets were loaded, the required weights were supported on wooden battens, arranged to transmit the loads to the fuselage through the front and rear tailplane spars (Fig.9). Water-filled tanks located in the fuselage nose were used as weights to counterbalance the tail loading. Details of fuselage section weights, applied loads and points of application, together with the resulting conditions at the attack stations are shown diagrammatically in Fig.1 and detailed in Table 1.

2.4 In the cases where the fuselage did not fail, the additional load to cause failure was applied by means of a cable,attached to the fuselage below the tailplane, which then passed under a pulley, secured to a strong point in the ground, vertically below the point of application of the load. The load was thus applied horizontally and, from a spring balance in the cable run, the magnitude of the load applied could be measured.

APPENDIX 2

STRESS ANALYSES OF DAMAGED FUSELAGE SECTIONS

1 METHOD OF ANALYSIS

1.1 Stress analyses were made of the four primary fuselage targets which had been subjected to continuous rod attack. The calculations were based on bending loads only and in view of the small amount of structure severed on the exit side and its location on or near the effective neutral axis of the damaged fuselage, exit damage was neglected.

The general method of analysis was the same as that used in the Boeing stress analysis reports on the B.29 aircraft and is described in Ref.4.

1.2 The method consists of determining initially the position of the neutral axis of the damaged fuselage section. The total effective cross-sectional area of the remaining structure is found and used to locate the position of the effective neutral axis. The total moment of inertia can then be found and substituted in the relation:-

$$f = \frac{My}{I}$$

where f = nominal stress

M = bending moment on section

y = distance from effective neutral axis

I = moment of inertia of section

Thus, the magnitude and position of the maximum nominal stresses in the damaged section may be determined.

The detailed calculations are given in Tables 1-4. For the purposes of comparison the maximum stresses under the actual trials loading and for the 1g level flight loading are shown.

TABLE 1 - Summary of continuous rod firings against fuselage targets

Firing No.	Rod size in. x in.	Direction of rod approach	Slant range ft	Rod mean velocity F.P.S.	Estimated rod striking velocity F.P.S.	Target	Attack station	Loading	Result of firing	Remarks
1	1/4 x 1/4	45° above dead abeam	32	3519	3311	B29 mid pressure Section (P)	768	1g flight loads 1.74 tons (3900 lb) at Stn.1059 giving B.M. = 2,159,800 lb in. S.F. = [illegible],835 lb At Stn.768	Fuselage failed	
						Victor rear fuselage (S)	980	No load	See Figs. 3 &11D	
2	3/16 x 3/16	45° above dead abeam	20	3504	3330	B29 mid pressure Section (P)	768	As for firing 1	Fuselage did not fail	Fuselage failed after additional load of 4260 lb applied at Stn.1059, approx. equivalent to 1½g loading
						B29 mid pressure Section (S)	768	No load	See Figs. 4 & 12B	
3	1/4 x 1/4	45° above dead abeam	32	3480	3276	B29 centre fuselage (P)	566	1g flight loads 3.08 tons (6900 lb) at Stn.1059 giving B.M. = 5,736,000 lb in. S.F. = 14,045 lb At Stn.566	Fuselage did not fail	Fuselage failed after additional load of 12052 lb applied at Stn.1059 approx. equivalent to 1¾g
		60° off dead astern				B29 centre fuselage (S)	566	No load	See Figs. 6 & 13E	
4	5/16 x 5/16	45° above dead abeam	25	3362	3152	B29 centre fuselage (P)	566	As for firing 3	Fuselage failed	
		60° off dead astern				B29 centre fuselage (S)	566	No load	See Figs. 8 & 14C,D	

(P) Denotes primary target (S) Denotes secondary target

TABLE 2

Details of continuous rod warheads used in lethality trials

Firing Nos.	Warhead type	Warhead weight lb	Warhead length in.	Warhead dia. in.	Rod size in. × in.	Rod Arrangement	Theoretical max.hoop dia. ft	Liner dia. in.	H.E. filling	H.E. filling weight lb
1 & 3	Red Dean (solid)	125	14.8	10.5	1/4 × 1/4	2-tier	37.3	5.12	RDX/TNT:60/40	25
2	Blue Jay type IC (solid)	48	10.9	8.0	3/16 × 3/16	2-tier	23.5	3.8	RDX/TNT:60/40	9
4	Red Dean (solid)	140	14.8	10.75	5/16 × 5/16	2-tier	29.7	5.35	RDX/TNT:60/40	25

All warheads were initiated by means of a centrally positioned No.33 electric detonator and a 14 drm C.E. pellet.

TABLE 3

Summary of rod damage to fuselage targets

Firing No.	Rod size in. x in.	Direction of rod approach	Target	Theoretical arc of strike on fuselage (from geometry) (A)°	Actual arc of strike on fuselage: Total (B)°	Above[1] Deg	Below[2] Deg	Percentage B/A	Approx. percentage of total fuselage structural C.S.A. severed on attack side (%)	Approx. percentage of total fuselage structural C.S.A. severed over whole fuselage section (%)	Additional structure severed	Result
1	1/4 x 1/4	45° above dead abeam	Stn.768 B29 fuselage	168	168	78	90	100	41	45	None	Fuselage failed
			Stn.980 Victor fuselage	180	170	82	88	95	31	33	None	-
2	3/16 x 3/16	45° above dead abeam	Stn.768 B29 fuselage	161	147	70	77	92	36	38	None	Fuselage failed with 1½g loading
			Stn.768 B29 fuselage	161	146	77	69	91	35	37	None	-
3	1/4 x 1/4	45° above dead abeam	Stn.566 B29 fuselage	166	123	50	73	74	41	46	None	Fuselage failed with 1½g loading
		60° off dead astern	Stn.566 B29 fuselage	133 *	124	77	47 *	94	38	40	2 frames	-
4	5/16 x 5/16	45° above dead abeam	Stn.566 B29 fuselage	163	156	78	78	96	44	51	1 frame	Fuselage failed
		60° off dead astern	Stn.566 B29 fuselage	135*	129	77	52	96	44	47	5 frames	-

NOTES: * Limited by absence of bomb doors

1 Angle of cut above line joining warhead and fuselage centres

2 Angle of cut below line joining warhead and fuselage centres

C.S.A. = Cross-sectional area

Stress analys

Firing No.1 -

(Bending loads only

Member (see Fig.2)	Distance of member from neutral axis in.	Effective skin area Tension in.^{2}	Compression in.^{2}	Stringer area in.^{2}	Total area in.^{2}
1	2	3	4	5	6
-	dy	-	-	-	A = (3) or (4) + (5)
H	58.3	0.378	-	0.395	0.773
I	53.5	0.378	-	0.122	0.500
J	47.8	0.338	-	0.402	0.740
K	41.5	0.297	-	0.122	0.419
L	34.7	0.297	-	0.301	0.598
M	27.5	0.297	-	0.173	0.470
N	20.1	0.297	-	0.279	0.576
O	12.7	0.297	-	0.301	0.598
P	5.5	0.297	-	0.173	0.470
Q	- 1.3	-	0.048	0.395	0.443
R	- 7.6	-	0.144	0.402	0.546
S	-13.3	-	0.048	1.478	1.526
T - T'	-15.8	-	2 × 0.048	2 × 0.173	0.442
U - U'	-18.1	-	2 × 0.048	2 × 0.395	0.886
V - V'	-22.0	-	2 × 0.122	2 × 0.402	1.048
W - W'	-24.8	-	2 × 0.031	2 × 0.395	0.852
X - X'	-26.5	-	2 × 0.031	2 × 0.173	0.408
Y	-27.1	-	0.100	0.402	0.502
Σ					11.797

$$\bar{y} = \frac{\Sigma(7)}{\Sigma(6)} = \frac{63.16}{11.797} = 5.35 \text{ in.}$$

Trials ben

1g bend

1

APPENDIX 2

TABLE 1

Stress analysis of damaged fuselage

Firing No.1 - 1/4 in. rod v. Stn.768

(Bending loads only, rod exit damage neglected)

skin area Compression in.^{2}	Stringer area in.^{2}	Total area in.^{2}	in.^{3}	Distance of member from effective neutral axis in.	Moment of inertia in.^{4}	Maximum stress (trial loading) lb/in.^{2}	Maximum stress (1g level flight loading) lb/in.^{2}
4	5	6	7	8	9	10	11
-	-	A = (3) or (4) + (5)	Ady = (2) × (6)	y = (2) - $\bar{y}$	$I = \Sigma Ay^2$ = (6) × (8)^2	$f = \frac{My}{I}$ = $\frac{M \times (8)}{\Sigma(9)}$	$f' = \frac{M'y}{I}$ = $\frac{M' \times (8)}{\Sigma(9)}$
-	0.395	0.773	45.0	52.95	2160	+11,500	+12,300
-	0.122	0.500	26.7	48.15	1160		
-	0.402	0.740	35.4	42.45	1330		
-	0.122	0.419	17.4	36.15	548		
-	0.301	0.598	20.7	29.35	515		
-	0.173	0.470	12.9	22.15	230		
-	0.279	0.576	11.58	14.75	125.3		
-	0.301	0.598	7.60	7.35	32.3		
-	0.173	0.470	2.58	0.15	0		
0.048	0.395	0.443	- 0.58	- 6.65	19.5		
0.144	0.402	0.546	- 4.15	-12.95	92.0		
0.048	1.478	1.526	-20.30	-18.65	530.7		
× 0.048	2 × 0.173	0.442	- 7.00	-21.15	197.5		
× 0.048	2 × 0.395	0.886	-16.04	-23.45	488		
× 0.122	2 × 0.402	1.048	-23.10	-27.35	784		
× 0.031	2 × 0.395	0.852	-21.13	-30.15	775		
× 0.031	2 × 0.173	0.408	-10.80	-31.85	415		
0.100	0.402	0.502	-13.60	-32.45	530	- 7,055	- 7,559
		11.797	+63.26		9932.3		

= 5.35 in.

Trials bending moment M = 2,159,800 lb in.
1g bending moment M' = 2,314,000 lb in.

2

APP

TAB

Stress analysis o

Firing No.2 - 3/16

(Bending loads only, ro

Member (See Fig.2)	Distance of member from neutral axis	Effective skin area		Stringer area	Total area	
		Tension	Compression			
	in.	$in.^2$	$in.^2$	$in.^2$	$in.^2$	in
1	2	3	4	5	6	7
-	dy	-	-	-	A = (3) or (4) +(5)	Ad = (2)
F	62.0	0.378	-	0.173	0.551	34
G	59.9	-	-	0.122	0.122	7
H	58.1	0.378	-	0.122	0.500	29
I	53.3	0.378	-	0.122	0.500	26
J	47.6	0.338	-	0.402	0.740	35
K	41.3	0.297	-	0.122	0.419	17
L	34.5	0.297	-	0.301	0.598	20
M	27.3	0.297	-	0.173	0.470	12
N	19.9	0.297	-	0.279	0.576	11
O	12.5	0.297	-	0.301	0.598	7
P	5.3	0.297	-	0.173	0.470	2
Q	- 1.5	-	0.048	0.395	0.443	- 0
R - R'	- 7.8	-	2 × 0.144	2 × 0.402	1.092	- 8
S - S'	-13.5	-	2 × 0.048	2 × 1.478	3.052	-41
T - T'	-16.0	-	2 × 0.048	2 × 0.173	0.442	- 7
U - U'	-18.3	-	2 × 0.048	2 × 0.395	0.886	-16
V - V'	-22.2	-	2 × 0.122	2 × 0.402	1.048	-23
W - W'	-25.0	-	2 × 0.031	2 × 0.395	0.852	-21
X - X'	-26.7	-	2 × 0.031	2 × 0.173	0.408	-10
Y	-27.1	-	0.100	0.402	0.502	-13
Σ					14.269	+61

$$\bar{y} = \frac{\Sigma(7)}{\Sigma(6)} = \frac{61.68}{14.269} = 4.3 \text{ in.}$$

Trials bending moment

1g bending moment

B.M. at failure

APPENDIX 2

TABLE 2

Stress analysis of damaged fuselage

Firing No.2 - 3/16 in. rod v. Stn.768

(Bending loads only, rod exit damage neglected)

Stringer area in.^{2}	Total area in.^{2}	in.^{3}	Distance of member from effective neutral axis in.	Moment of inertia in.^{4}	Maximum stress (trial loading) lb/in.^{2}	Maximum stress (1g level flight loading) lb/in.^{2}	Maximum stress at failure lb/in.^{2}
5	6	7	8	9	10	11	12
-	A $= (3)$ or $(4) + (5)$	Ady $= (2) \times (6)$	y $= (2) - \bar{y}$	$I = \Sigma Ay^2$ $= (6) \times (8)^2$	$f = \frac{My}{I}$ $= \frac{M \times (8)}{\Sigma(9)}$	$f' = \frac{M'y}{I}$ $= \frac{M' \times (8)}{\Sigma(9)}$	$f'' = \frac{M'y}{I}$ $= \frac{M'' \times (8)}{\Sigma(9)}$
0.173	0.551	34.2	57.7	1830	+10.400	+11.180	+16.400
0.122	0.122	7.3	55.6	378			
0.122	0.500	29.0	53.8	1440			
0.122	0.500	26.6	49.0	1200			
0.402	0.740	35.2	43.3	1382			
0.122	0.419	17.3	37.0	575			
0.301	0.598	20.6	30.2	546			
0.173	0.470	12.8	23.0	249			
0.279	0.576	11.4	15.6	140			
0.301	0.598	7.48	8.2	40.2			
0.173	0.470	2.49	1.0	0.5			
0.395	0.443	- 0.67	- 5.8	14.9			
2 × 0.402	1.092	- 8.56	-12.1	160.2			
2 × 1.478	3.052	-41.20	-17.8	970			
2 × 0.173	0.442	- 7.10	-20.3	182.5			
2 × 0.395	0.886	-16.16	-22.6	453.0			
2 × 0.402	1.048	-23.30	-26.5	738			
2 × 0.395	0.852	-21.25	-29.3	734			
2 × 0.173	0.408	-10.88	-31.0	392			
0.402	0.502	-13.57	-31.4	495	-5.690	-6.100	-8.940
	14.269	+61.68		11.920.3			

Trials bending moment M = 2,159,800 lb in.
1g bending moment M' = 2,314,000 lb in.
B.M. at failure M'' = 3,394,800 lb in.

2

A

Stress analy
Firing No.3
(Bending loads onl

Member (See Fig.2)	Distance of member from neutral axis in.	Effective skin area Tension in.^{2}	Compression in.^{2}	Stringer area in.^{2}	Total area in.^{2}
1	2	3	4	5	6
-	dy	-	-	-	A = (3) or (4) + (5)
B	64.8	0.358	-	0.395	0.753
C	62.7	0.358	-	0.395	0.753
D	59.3	0.358	-	0.198	0.556
E	56.9	-	-	0.122	0.122
F	54.6	0.408	-	0.395	0.803
G	48.8	0.457	-	0.122	0.579
H	42.0	0.457	-	0.301	0.758
I	34.4	0.457	-	0.122	0.579
J	26.1	0.457	-	0.301	0.758
K	17.4	0.457	-	0.173	0.630
L	8.5	0.457	-	0.173	0.630
M	0.4	0.457	-	0.301	0.758
N	- 9.1	-	0.078	0.173	0.251
O	-17.4	-	0.078	0.173	0.251
P - P'	-19.9	-	2 × 0.126	2 × 0.732	1.716
Q - ½Q'	-25.0	-	2 × 0.078	1½× 0.395	0.748
R - R'	-19.9	-	2 × 0.172	2 × 0.940	2.224
S	-31.8	-	0.078	0.395	0.473
T - T'	-33.5	-	2 × 0.201	2 × 2.534	5.470
Σ					18.812

$\bar{y} = \frac{\Sigma(7)}{\Sigma(6)} = \frac{-6.13}{18.812} = -0.3$ in. apprx.

Trials b
1g b
B.M. a

1

APPENDIX 2

TABLE 3

Stress analysis of damaged fuselage
Firing No.3 - 1/4 in. rod v. Stn.566
(Bending loads only, rod exit damage neglected)

...area ...sion	Stringer area	Total area		Distance of member from effective neutral axis	Moment of inertia	Maximum stress (trial loading)	Maximum stress (1 g level flight loading)	Maximum stress at failure
...^{2}	in.^{2}	in.^{2}	in.^{3}	in.	in.^{4}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}
	5	6	7	8	9	10	11	12
	-	A = (3) or (4) + (5)	Ady = (2) × (6)	y = (2) - $\bar{y}$	I = ΣAy^2 = (6) × $(8)^2$	$f = \frac{My}{I} = \frac{M \times (8)}{\Sigma(9)}$	$f' = \frac{M'y}{I} = \frac{M' \times (8)}{\Sigma(9)}$	$f'' = \frac{M''y}{I} = \frac{M'' \times (8)}{\Sigma(9)}$
	0.395	0.753	48.7	65.1	3180	15,680	13,000	22,600
	0.395	0.753	47.2	63.0	2980			
	0.198	0.556	33.0	59.6	1971			
	0.122	0.122	6.97	57.2	399			
	0.395	0.803	43.8	54.9	2415			
	0.122	0.579	28.2	49.1	1390			
	0.301	0.758	31.8	42.3	1352			
	0.122	0.579	19.9	34.7	697			
	0.301	0.758	19.7	26.4	529			
	0.173	0.630	10.9	17.7	197.5			
	0.173	0.630	5.35	8.8	48.7			
	0.301	0.758	0.30	0.7	0.4			
...78	0.173	0.251	- 2.28	- 8.8	19.4			
...78	0.173	0.251	- 4.37	-17.1	73.6			
...86	2 × 0.732	1.716	-34.20	-19.6	661.0			
...78	1½ × 0.395	0.748	-18.70	-24.7	457.0			
...72	2 × 0.940	2.224	-44.40	-19.6	858.0			
...78	0.395	0.473	-15.0	-31.5	470.0			
...1	2 × 2.534	5.470	-183.0	-33.2	6040.0	-8,020	-6,660	-11,900
		18.812	- 6.13		23.738.6			

...prx.

Trials bending moment M = 5,736,000 lb in.
1g bending moment M' = 4,763,000 lb in.
B.M. at failure M" = 8,276,000 lb in.

2

APPENDIX 2

TABLE 4

Stress analysis of dama

Firing No.4 - 5/16 in. ro

(Bending loads only, rod exit

Number (see Fig.2)	Distance of member from neutral axis	Effective skin area		Stringer area	Total area	
		Tension	Compression			
	in.	in.^{2}	in.^{2}	in.^{2}	in.^{2}	in.
1	2	3	4	5	6	7
-	dy	-	-	-	A = (3) or (4) + (5)	Ady = (2) ×
F	63.9	0.408	-	0.395	0.803	51.
G	58.1	0.457	-	0.122	0.579	33.
H	51.3	0.457	-	0.301	0.758	38.
I	43.7	0.457	-	0.122	0.579	25.
J	35.4	0.457	-	0.301	0.758	26.
K	26.7	0.457	-	0.173	0.630	16.
L	17.8	0.457	-	0.173	0.630	11.
M	8.9	0.457	-	0.301	0.758	6.
N	0.2	-	0.078	0.173	0.251	0.
O	- 8.1	-	0.078	0.173	0.251	- 2.
P	-10.6	-	0.126	0.732	0.858	- 9.
Q - Q'	-15.7	-	2 × 0.078	2 × 0.395	0.946	-14.
R - R'	-10.6	-	2 × 0.172	2 × 0.940	2.224	-23.
S - S'	-22.5	-	2 × 0.078	2 × 0.395	0.946	-21.
T - T'	-24.2	-	2 × 0.201	2 × 2.534	5.470	-132.
Σ					16.441	+ 8.

$$\bar{y} = \frac{\Sigma(7)}{\Sigma(6)} = \frac{+8.17}{16.441} = 0.5 \text{ in.}$$

Trials bending moment M

1g bending moment M'

APPENDIX 2

TABLE 4

Stress analysis of damaged fuselage

Firing No.4 - 5/16 in. rod v. Stn.566

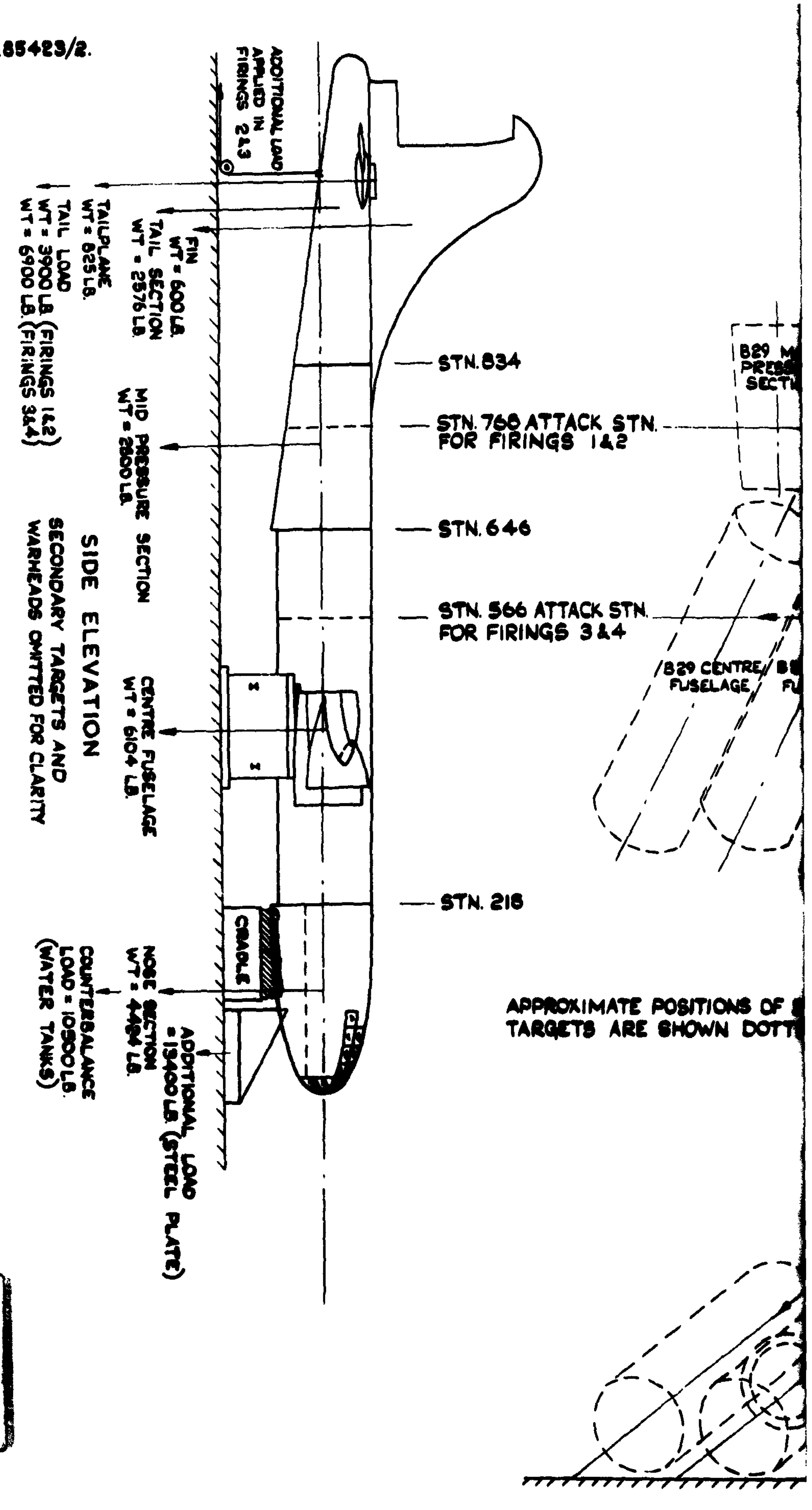
(Bending loads only, rod exit damage neglected)

Stringer area in.^{2}	Total area in.^{2}	in.^{3}	Distance of member from effective neutral axis in.	Moment of inertia in.^{4}	Maximum stress (trial loading) lb/in.^{2}	Maximum stress (1g level flight) loading) lb/in.^{2}
5	6	7	8	9	10	11
-	$A = (3)$ or $(4)+(5)$	$Ady = (2)\times(6)$	$y = (2) - \bar{y}$	$I = \Sigma Ay^2 = (6)\times(8)^2$	$f = \frac{My}{I} = \frac{M\times(8)}{\Sigma(9)}$	$f' = \frac{M'y}{I} = \frac{M'\times(8)}{\Sigma(9)}$
0.395	0.803	51.2	63.4	3220	+25,500	+21,100
0.122	0.579	33.6	57.6	1915		
0.301	0.758	38.8	50.8	1950		
0.122	0.579	25.3	43.2	1077		
0.301	0.758	26.8	34.9	925		
0.173	0.630	16.8	26.2	432		
0.173	0.630	11.2	17.3	188		
0.301	0.758	6.75	8.4	53.5		
0.173	0.251	0.50	- 0.3	0		
0.173	0.251	- 2.03	- 8.6	18.6		
0.732	0.858	- 9.05	-11.1	105.1		
2 × 0.395	0.946	-14.80	-16.2	248.0		
2 × 0.940	2.224	-23.70	-11.1	274.0		
2 × 0.395	0.946	-21.20	-23.0	500.0		
2 × 2.534	5.470	-132.0	-24.7	3335.0	-9,950	-8,280
	16.441	+ 8.17		1.4241.2		

Trials bending moment M = 5,736,000 lb in.

1g bending moment M' = 4,763,000 lb in.

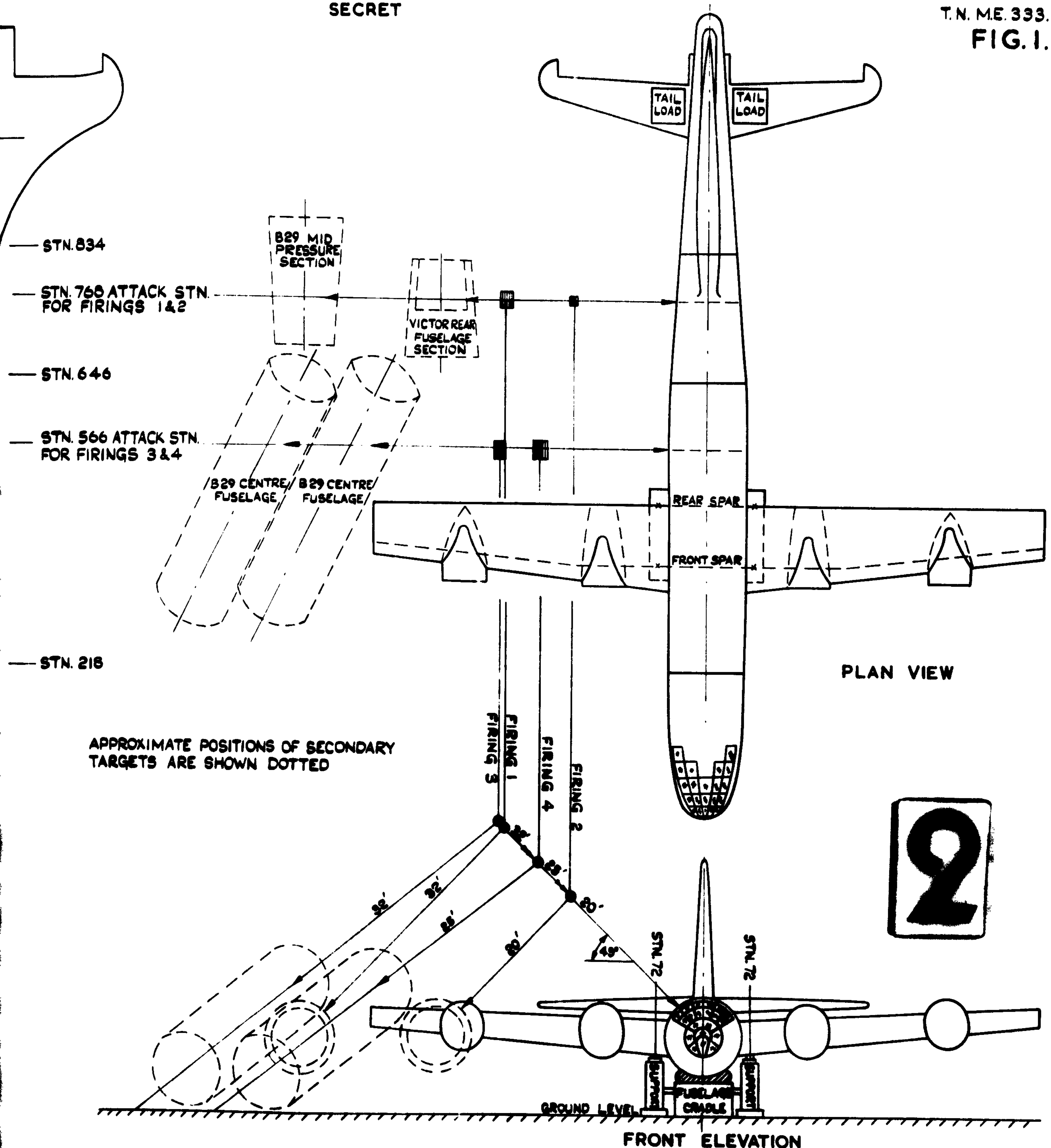
2



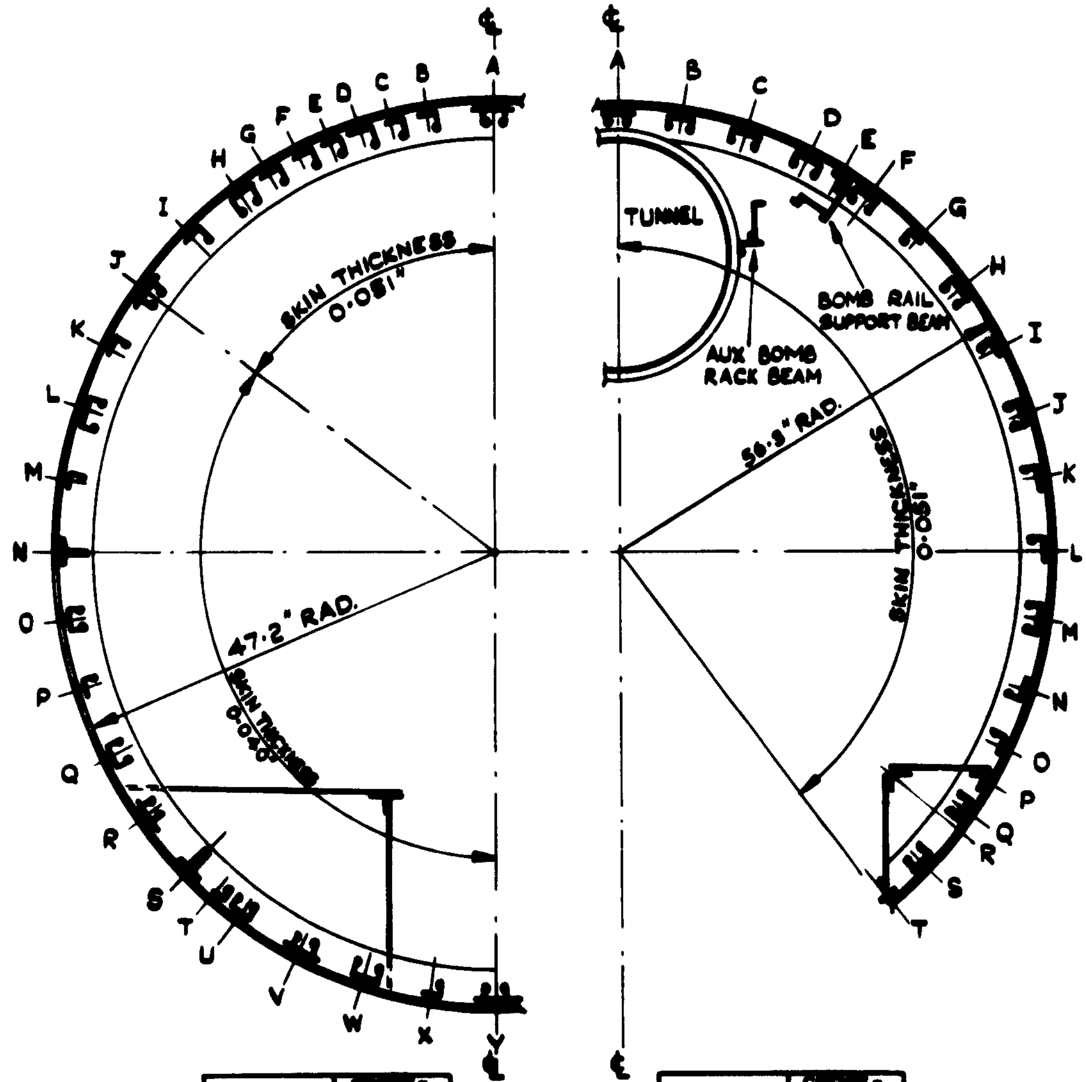
1

FIG. 1. LAYOUT OF FUSELAGE TARGETS

FIG. 1.



FUSELAGE TARGETS FOR CONTINUOUS ROD WARHEAD FIRINGS. (SCALE 1/144)



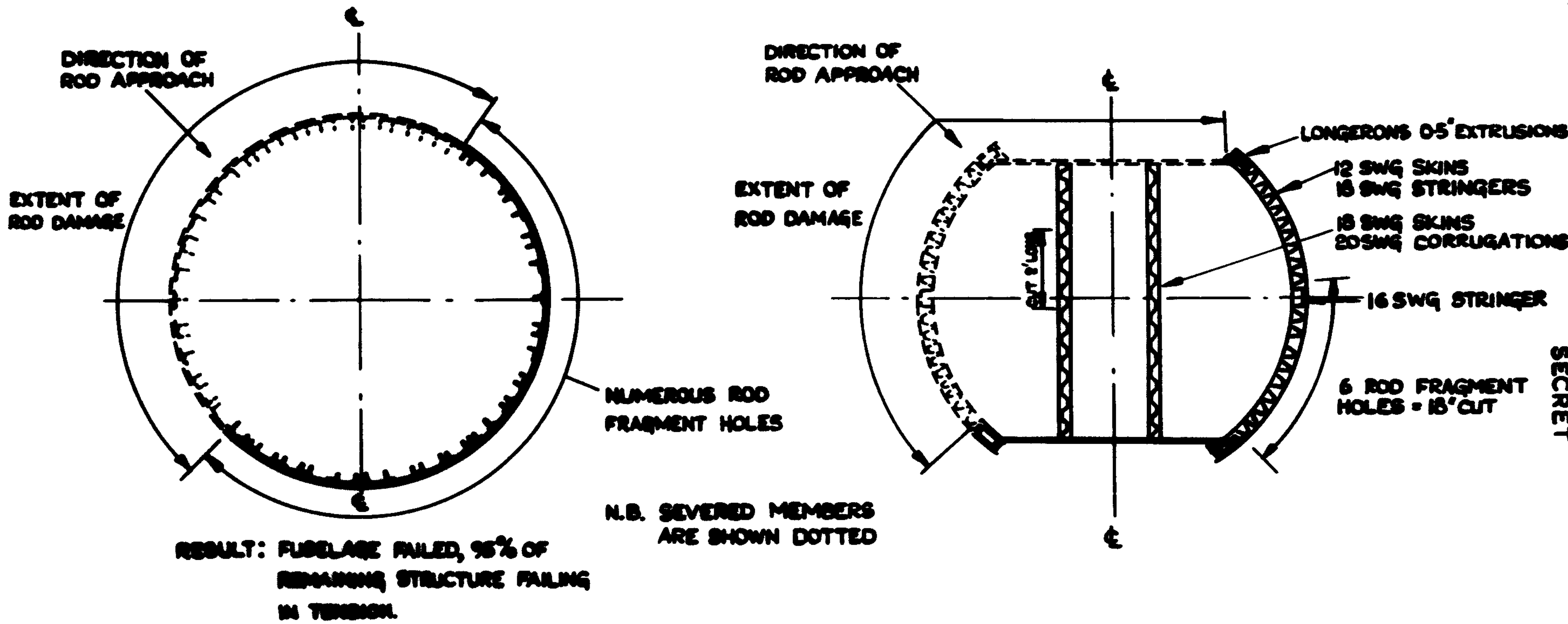
STRUCTURAL MEMBERS	CROSS-SECTIONAL AREA SQ. IN.
S	1·478
A.J.R.V.Y.	0·402
Q.U.W.H.	0·306
L.O.	0·301
N	0·279
D.F.B.M.P.T.X.	0·173
C.E.G.I.K.	0·1[illegible]
SKIN (0·051")	2·26
SKIN (0·040)	4·16

STN. 768
(MID CREW COMPARTMENT)

STRUCTURAL MEMBERS	CROSS-SECTIONAL AREA SQ. IN.
R	0·540
T	2·884
P	0·732
A	0·402
B.F.Q.S.C.	0·306
H.J.M	0·301
D	0·1[illegible]
K.L.N.O.	0·173
E.G.I.	0·122
SKIN (0·051")	7·14

566
STN. ~~768~~
(AFT BOMB BAY)

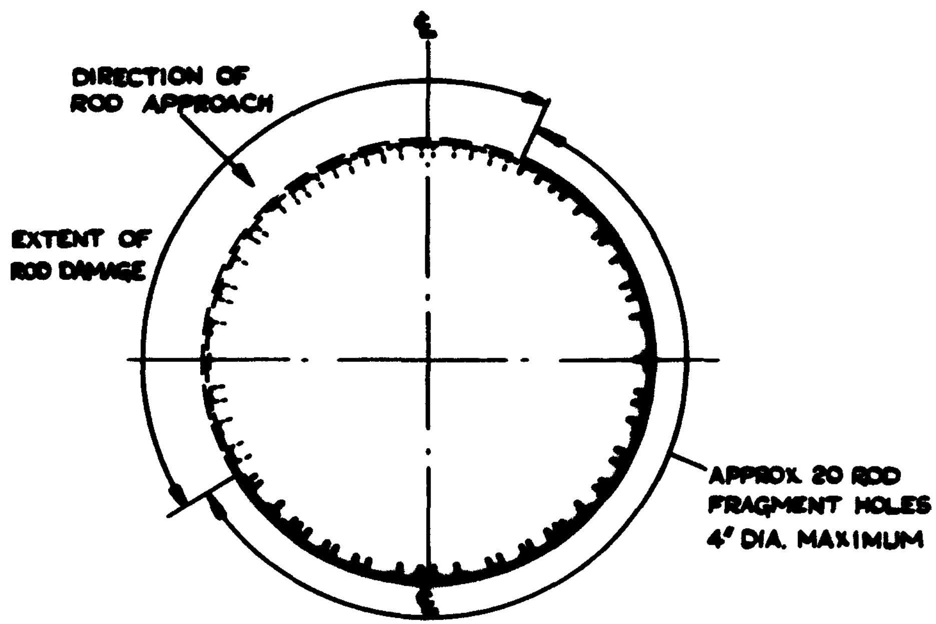
FIG. 2. CROSS-SECTIONS OF B.29 FUSELAGE AT ATTACK STATIONS.



PRIMARY TARGET
STN. 768 OF LOADED B.29 FUSELAGE

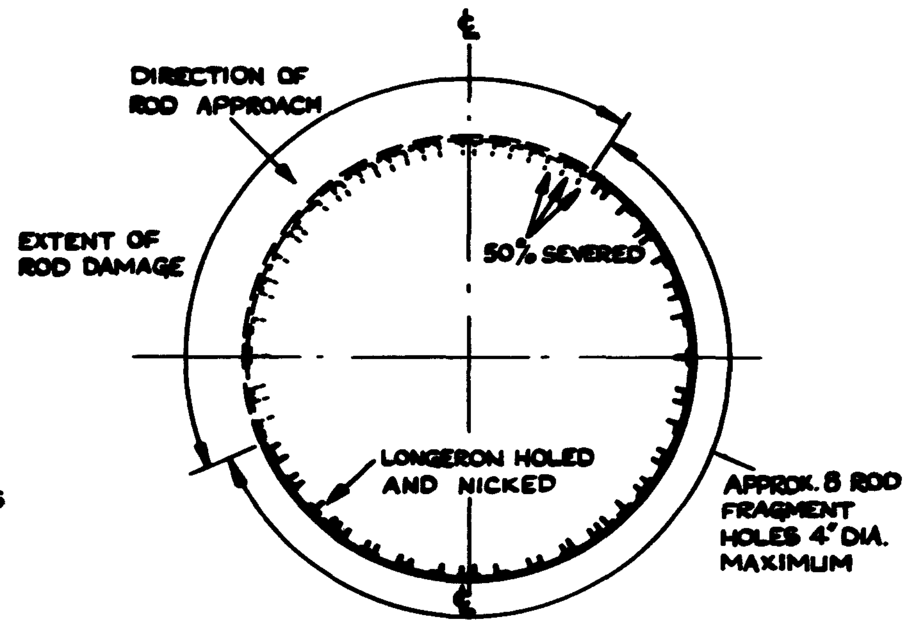
SECONDARY TARGET
STN. 980 OF UNLOADED VICTOR FUSELAGE

FIG. 3. FIRING. I. RECORD OF ROD DAMAGE TO PRIMARY AND SECONDARY TARGETS (1/4 IN. ROD).



RESULT: FUSELAGE DID NOT FAIL.
FAILED AFTER APPLICATION
OF ADDITIONAL 4420 LB. AT STN. 1059
EQUIVALENT TO 1·5g TOTAL LOAD

PRIMARY TARGET
STN. 768 OF LOADED B.29 FUSELAGE



N.B. SEVERED MEMBERS
ARE SHOWN DOTTED

SECONDARY TARGET
STN. 768 OF UNLOADED B.29 FUSELAGE SECTION

FIG. 4. FIRING. 2. RECORD OF ROD DAMAGE TO PRIMARY & SECONDARY TARGETS (3/16 IN. ROD).

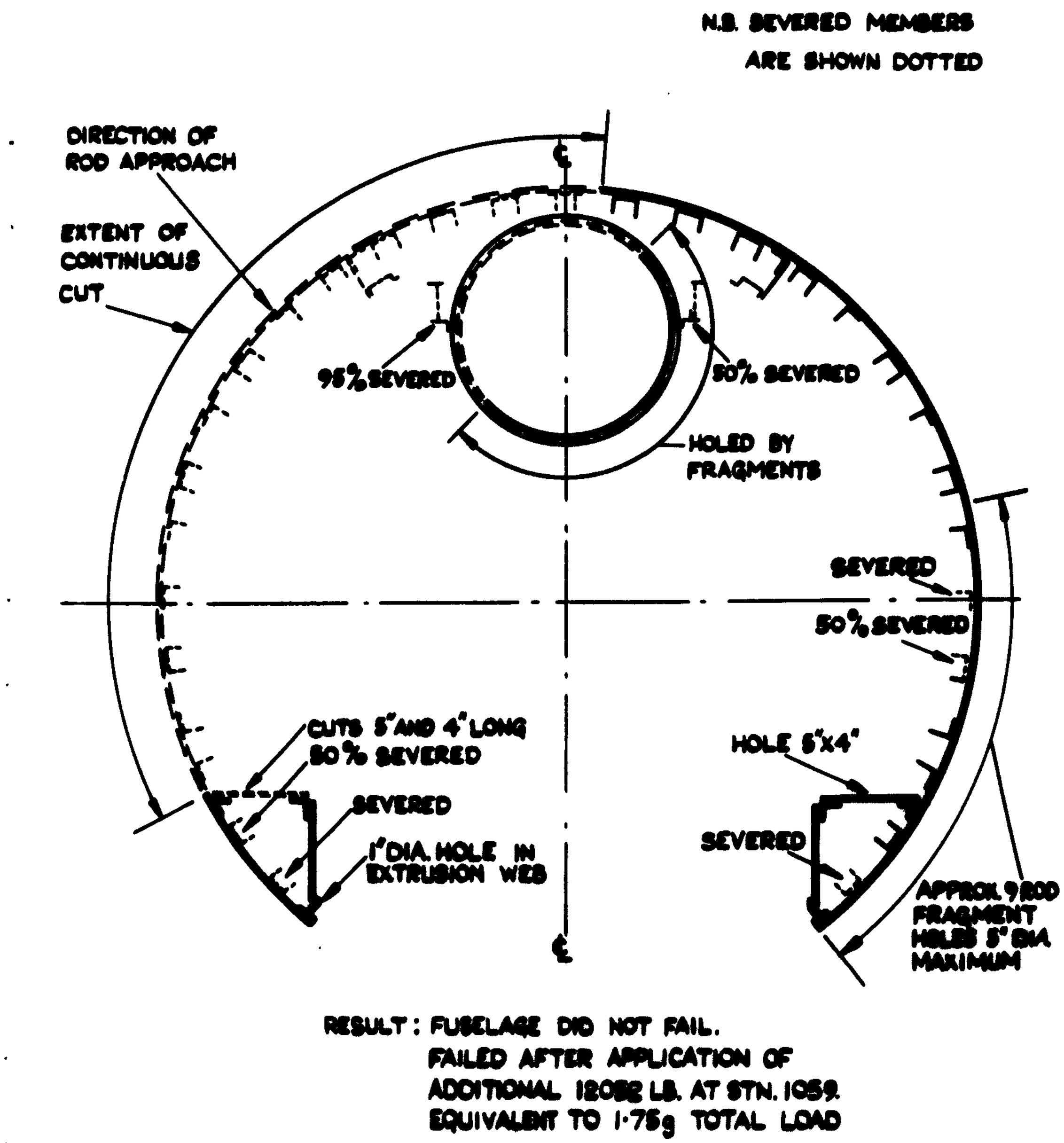
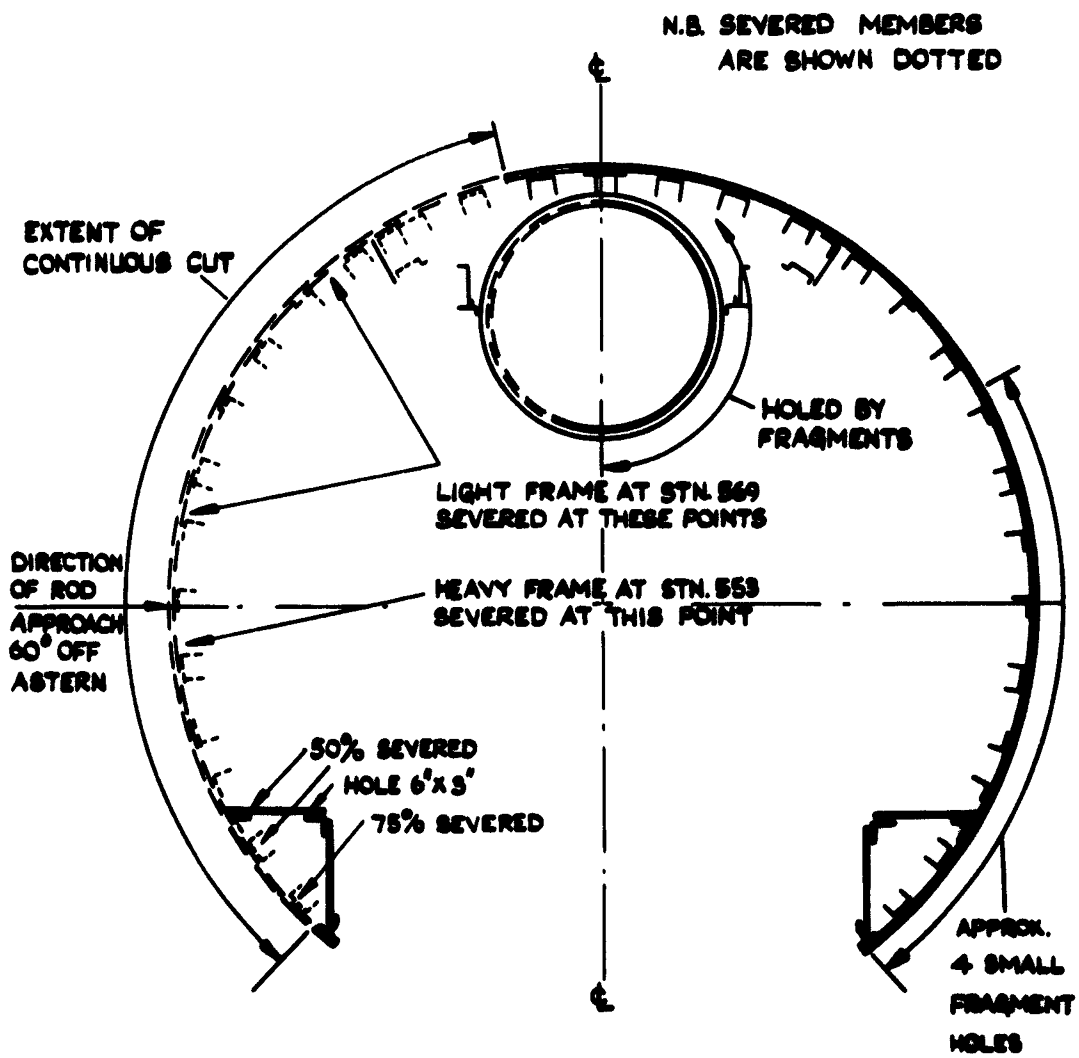
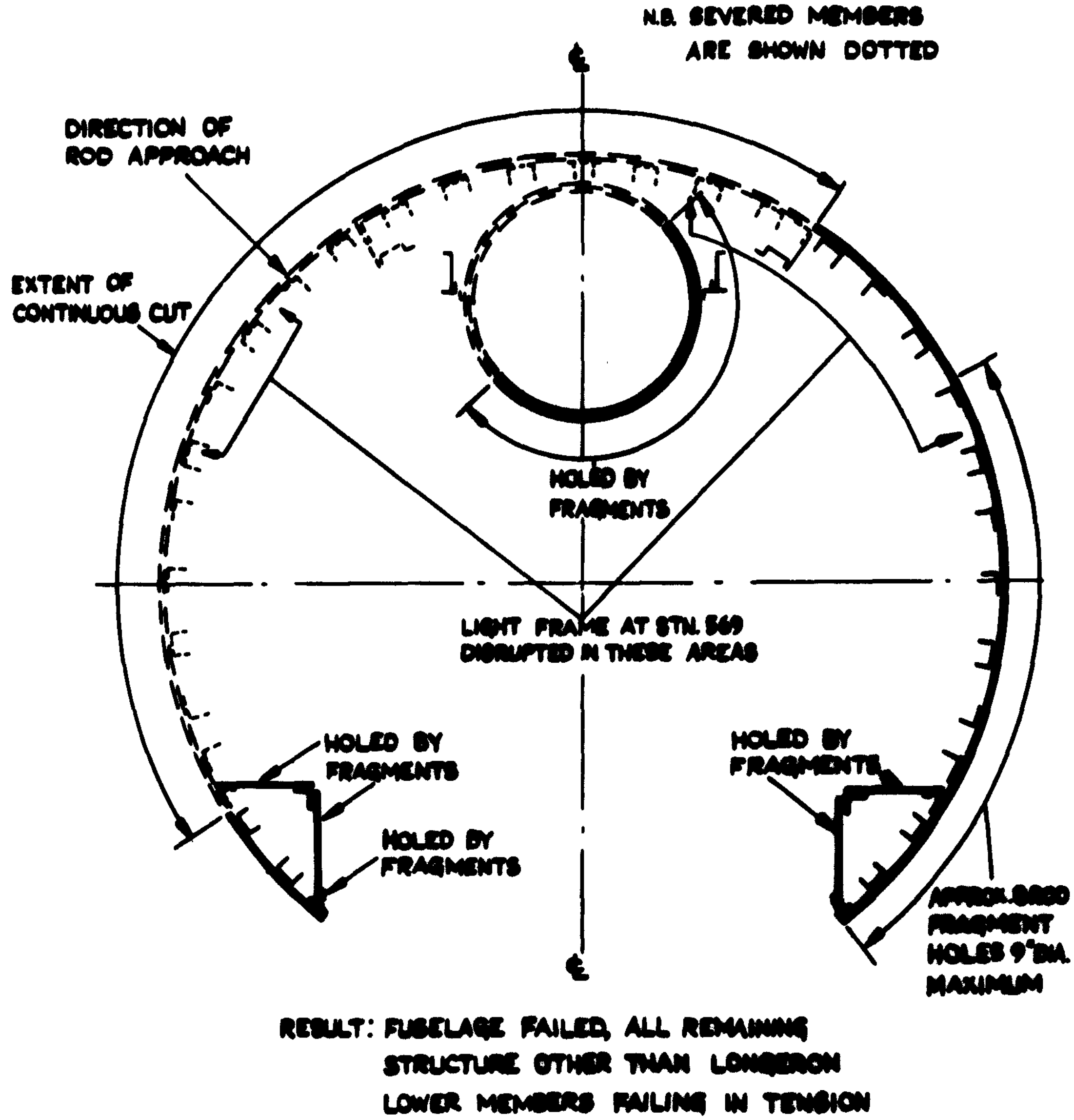


FIG. 5. FIRING 3. RECORD OF ROD DAMAGE TO PRIMARY TARGET (1/4 IN. ROD)



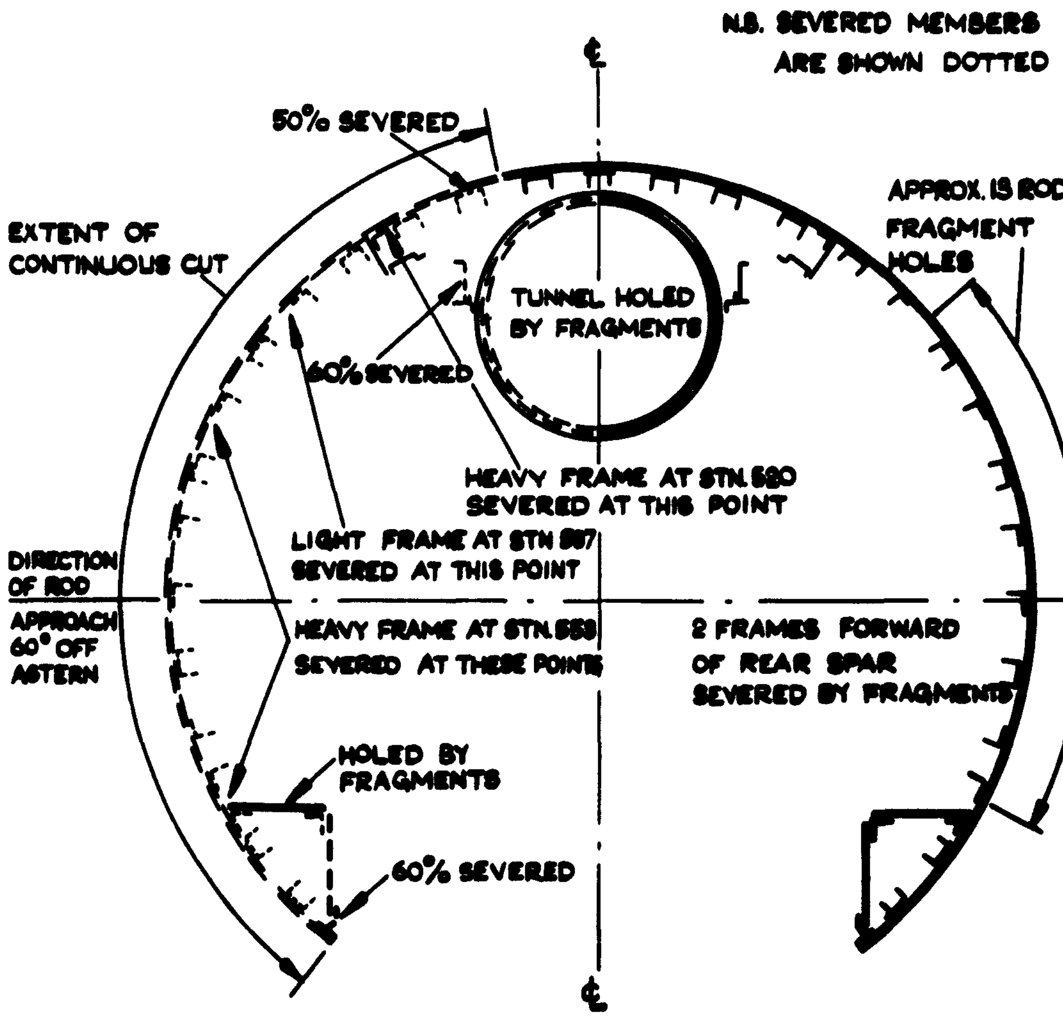
STNS. 537 TO 587 OF UNLOADED B.29 FUSELAGE SECTION

FIG. 6. FIRING. 3. RECORD OF ROD DAMAGE TO SECONDARY TARGET (¼ IN ROD)



STN. 566 OF LOADED B.29 FUSELAGE

FIG. 7. FIRING 4. RECORD OF ROD DAMAGE TO PRIMARY TARGET (5/16 IN. ROD)



STNS. 520 TO 587 OF UNLOADED B.29 FUSELAGE SECTION

FIG. 8. FIRING. 4. RECORD OF ROD DAMAGE TO SECONDARY TARGET (5/16 IN. ROD)

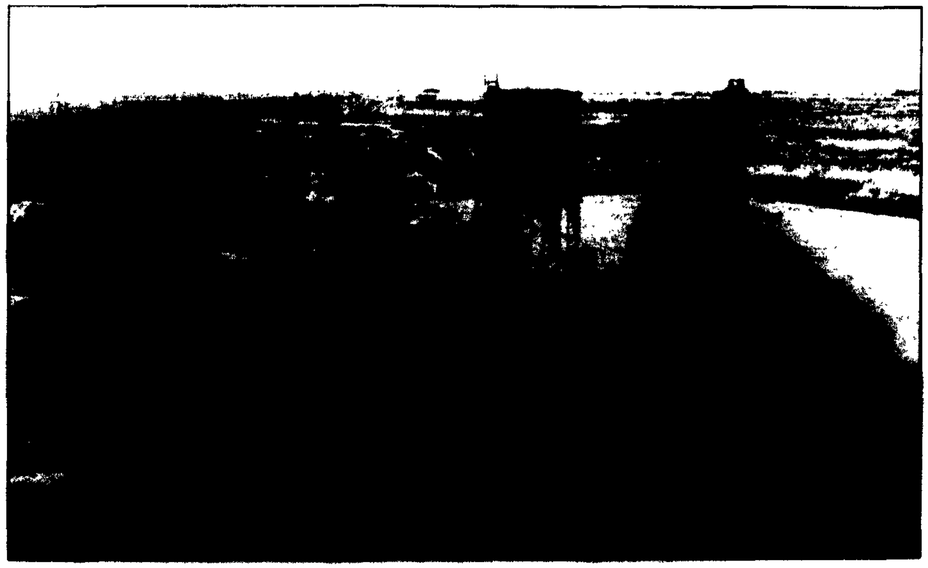


FIG.9. TYPICAL LAYOUT SHOWING PRIMARY AND SECONDARY TARGETS (FIRING 3)

FIG.10. TYPICAL LAYOUT SHOWING PRIMARY AND SECONDARY TARGETS (FIRING 4)

R.A.E. 151434 61

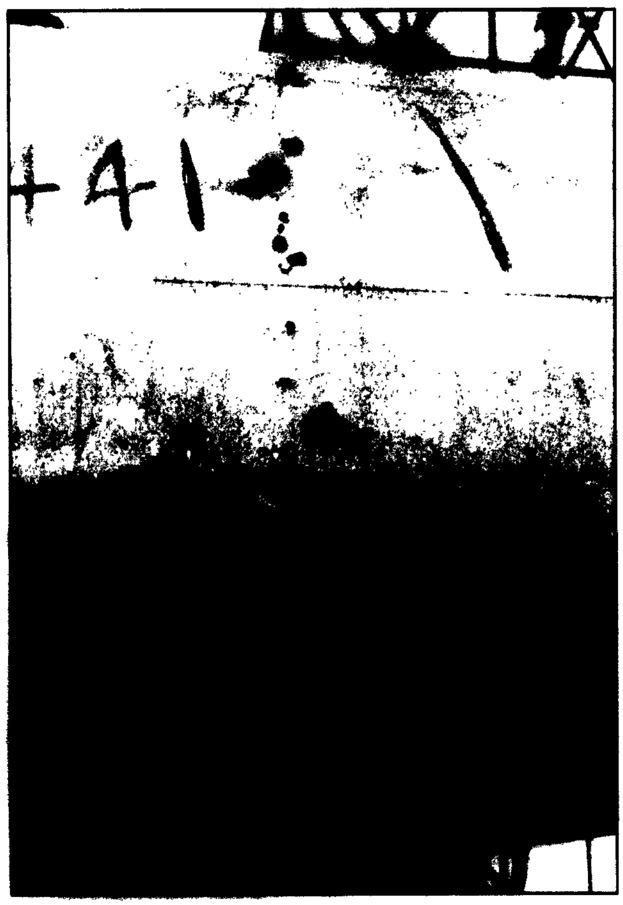
FIG.11a. FIRING 1. PRIMARY TARGET. ROD DAMAGE TO ATTACK SIDE SHOWING FAILURE (½ inch ROD. STN.768)

FIG.11b. FIRING 1. PRIMARY TARGET. EXIT SIDE OF FUSELAGE AFTER FAILURE (½ inch ROD. STN.768)

FIG.11c. FIRING I. SECONDARY TARGET. VICTOR REAR FUSELAGE BEFORE FIRING (½ inch ROD. STN.980)

FIG.11d. FIRING I. SECONDARY TARGET. VICTOR REAR FUSELAGE AFTER FIRING (½ inch ROD. STN.980)

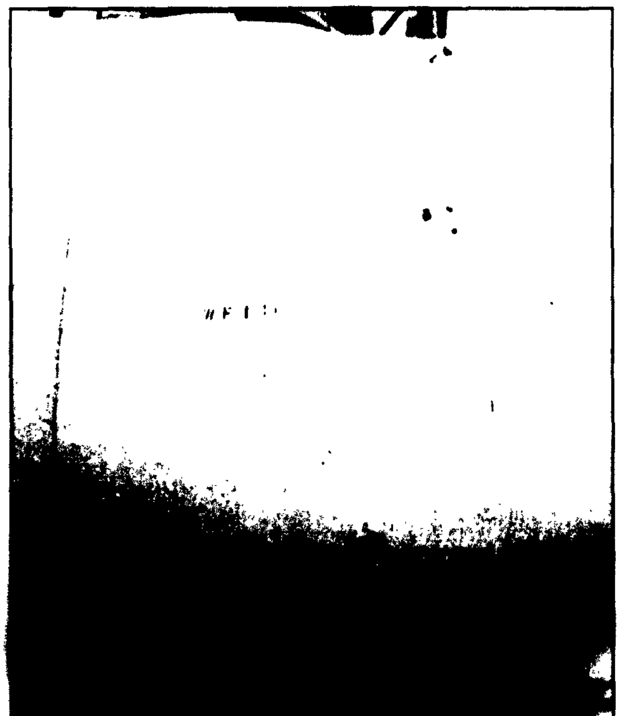
ATTACK SIDE



EXIT SIDE

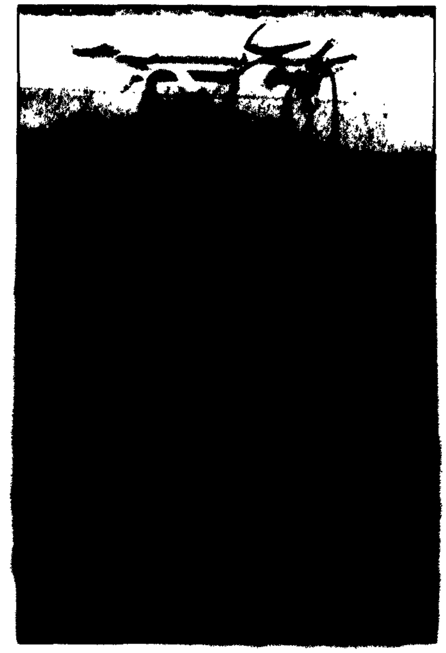
FIG.12a. FIRING 2. PRIMARY TARGET. DAMAGE TO FUSELAGE AFTER FIRING ($\frac{1}{4}$ inch ROD. STN.768)

ATTACK SIDE



EXIT SIDE

FIG.12b. FIRING 2. SECONDARY TARGET. DAMAGE TO FUSELAGE AFTER FIRING ($\frac{1}{16}$ inch ROD. STN.768)



EXTERIOR

INTERIOR

FIG.13a. FIRING 3. PRIMARY TARGET. ROD DAMAGE TO ATTACK SIDE OF FUSELAGE ($\frac{1}{4}$ inch ROD. STN.566)

EXTERIOR

INTERIOR

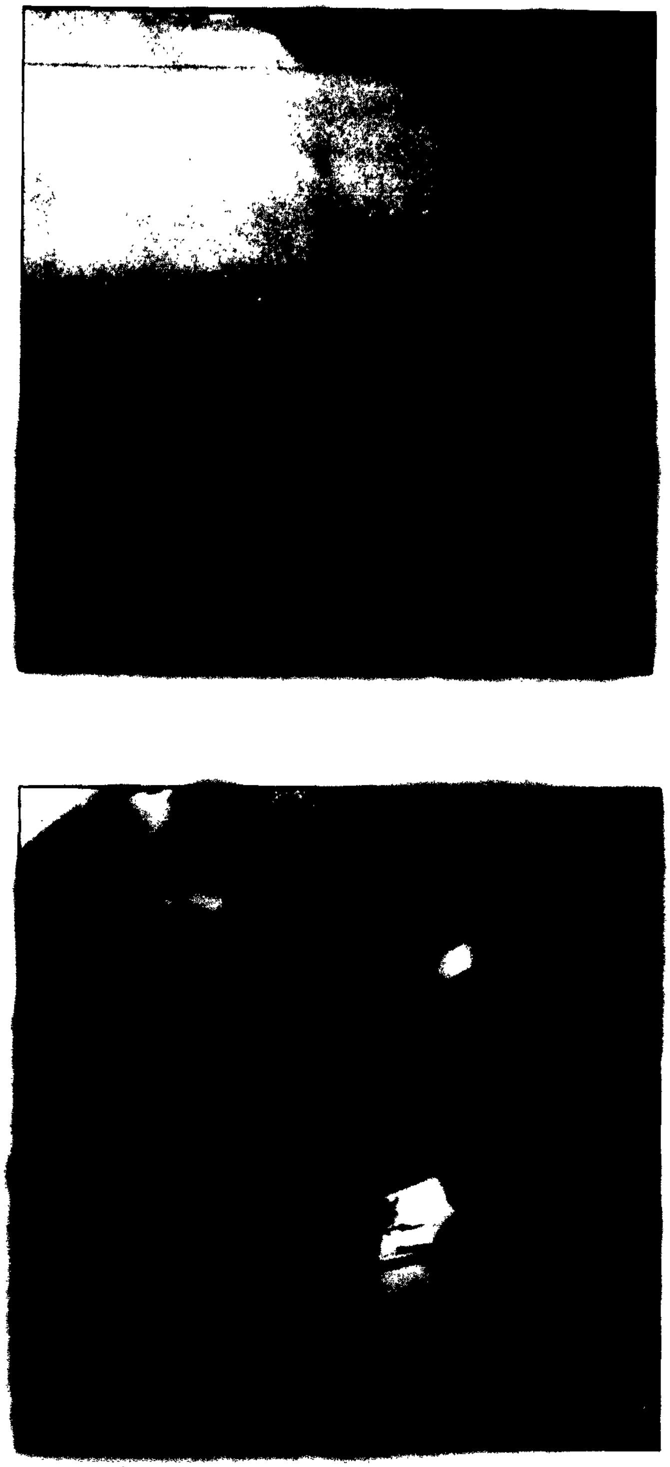
FIG.13b. FIRING 3. PRIMARY TARGET. ROD DAMAGE TO EXIT SIDE OF FUSELAGE (½ inch ROD. STN.566)

EXTERIOR

INTERIOR

FIG.13c. FIRING 3. PRIMARY TARGET. FAILURE OF ATTACK SIDE OF FUSELAGE AFTER APPLICATION OF ADDITIONAL LOAD (½ inch ROD. STN.566)

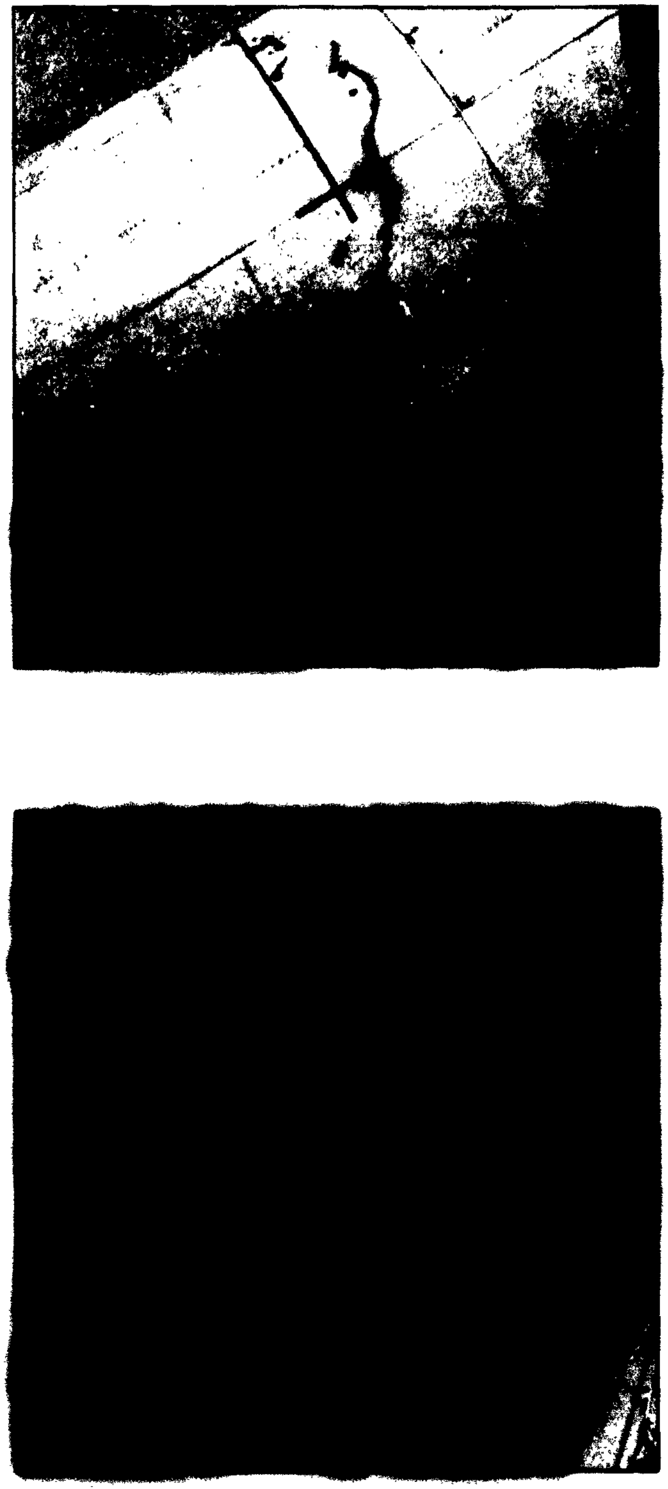
R.A.E. 151441 61



EXTERIOR

INTERIOR

FIG.13d. FIRING 3. PRIMARY TARGET. FAILURE OF EXIT SIDE OF FUSELAGE AFTER APPLICATION OF ADDITIONAL LOAD (¼ inch ROD. STN.566)

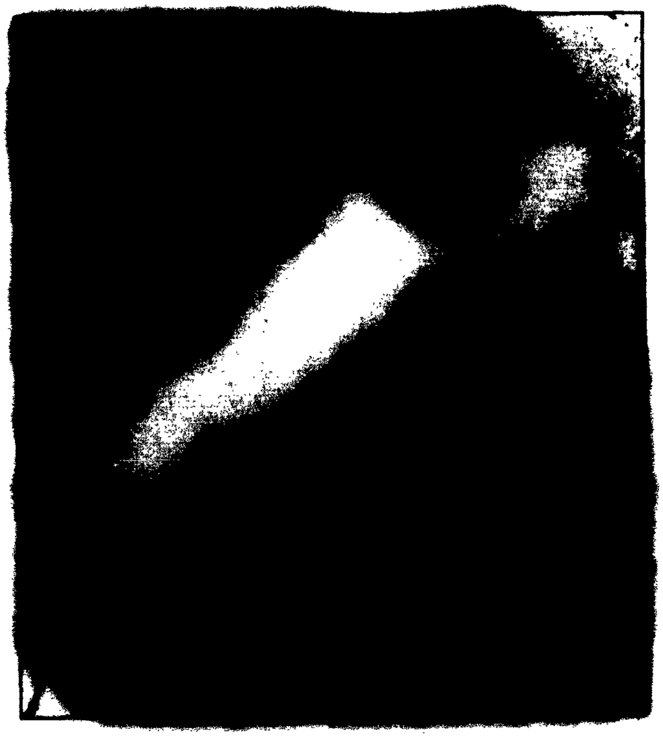


EXTERIOR

INTERIOR

FIG.13e. FIRING 3. SECONDARY TARGET. ROD DAMAGE TO ATTACK SIDE OF FUSELAGE (¼ inch ROD. STN.566, 60° OFF DEAD ASTERN)

EXTERIOR



INTERIOR

FIG. 14a. FIRING 4. PRIMARY TARGET. ROD DAMAGE TO ATTACK SIDE OF FUSELAGE ($\frac{1}{16}$ inch ROD. STN.566)

R.A.E. 151444 61

EXTERIOR

INTERIOR

FIG.14b. FIRING 4. PRIMARY TARGET. ROD DAMAGE TO EXIT SIDE OF FUSELAGE ($\frac{1}{16}$ inch ROD. STN.566)

R.A.E. 151445 61

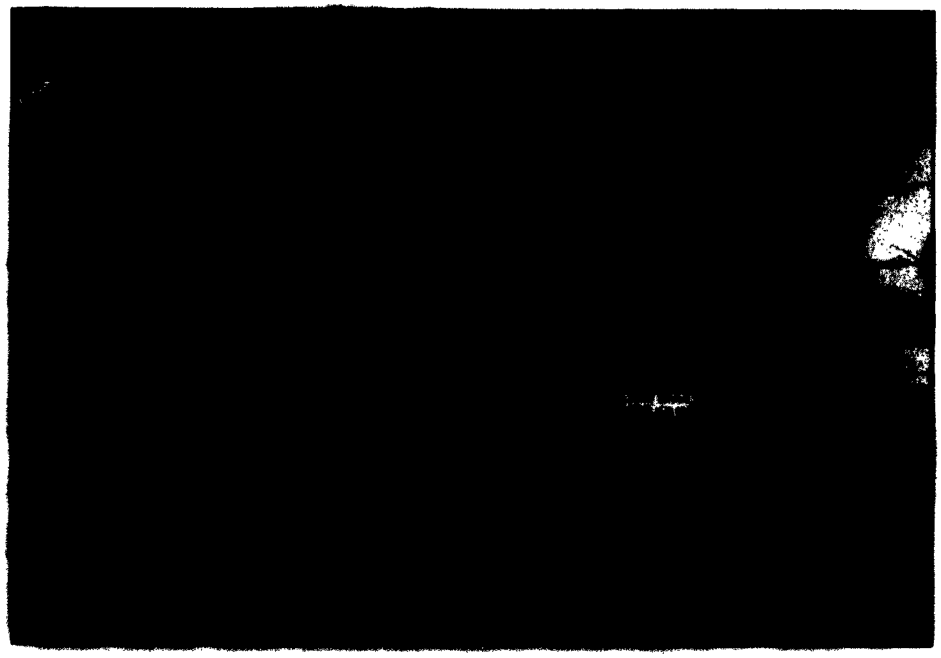


FIG.14c. FIRING 4. SECONDARY TARGET. ROD DAMAGE TO ATTACK SIDE EXTERIOR ($\frac{1}{16}$ inch ROD. STN.566, 60° OFF DEAD ASTERN)

R.A.E. 151446 61

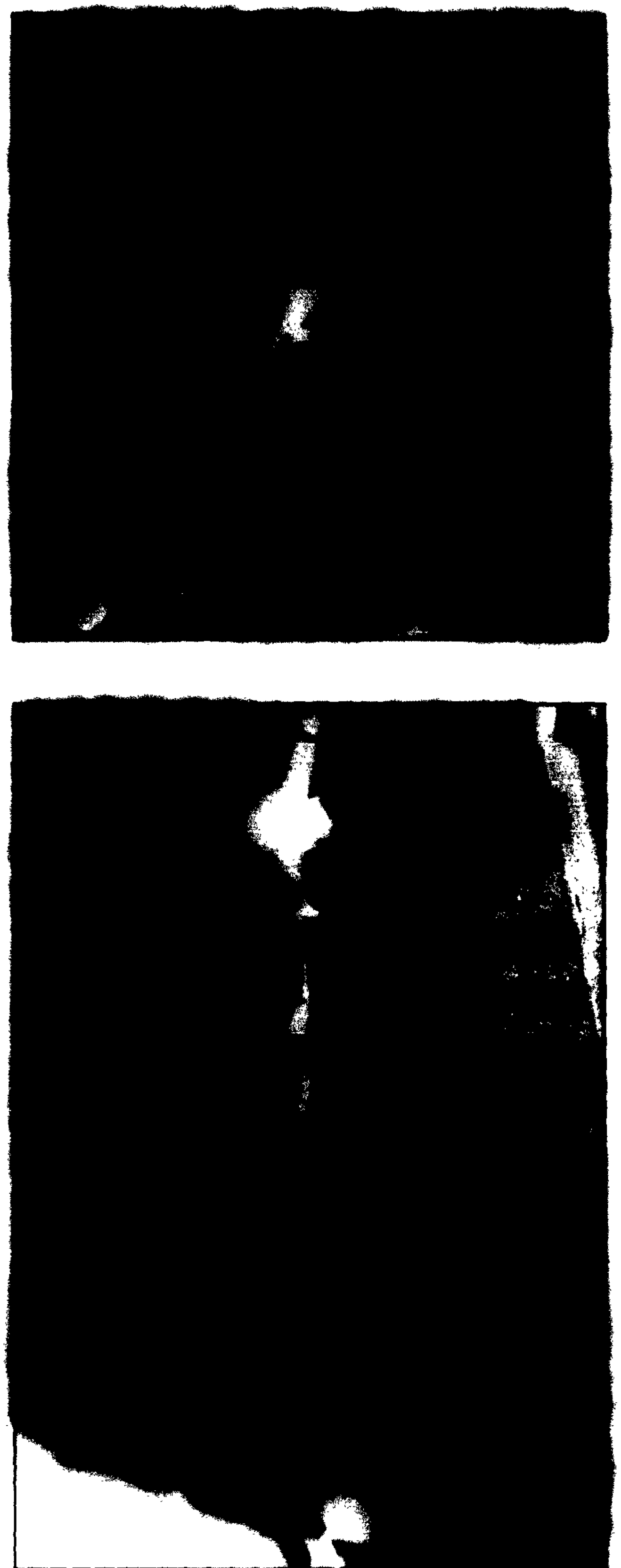


FIG.14d. FIRING 4. SECONDARY TARGET. ROD DAMAGE TO ATTACK SIDE INTERIOR ($\frac{1}{4}$ inch ROD. STN.566, 60° OFF DEAD ASTERN)

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This Note records the results of the static detonations of 3/16, 1/4 and 5/16 inch square-section continuous-rod warheads, against Boeing B29 aircraft fuselages, four of which were loaded to simulate straight and level flight conditions at the attack station. In the attack of the mid pressure section (unpressurised) from 45° above abeam, only the 1/4 and 5/16 inch square section rods were capable of causing complete failure of the fuselage, whilst in the rear bomb bay section (aft of the wings) only the 5/16 inch rod produced a similar failure of the target.

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Stress analyses have been made of the damaged targets to assist in the determination of the mechanism of target failure and of possible factors influencing rod effectiveness against aircraft fuselages. Some proposals for further work are included.

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